

What is claimed is:

1. A method for determining a thickness of a surficial thin-film layer on a substrate as the thin-film layer is being subjected to a process
5 resulting in a change in thickness of the thin-film layer, the method comprising:
- (a) directing a probe light onto a region of a surface of the thin-film layer to produce a signal light propagating from the thin-film layer;
 - (b) detecting the signal light;
 - 10 (c) measuring a spectral characteristic of the signal light from the detected signal light to produce a spectral-characteristic signal;
 - (d) calculating a value of a parameter of the spectral-characteristic signal that is a function of the thickness of the thin-film layer; and
 - (e) from the calculated value of the parameter, determining the
15 thickness of the thin-film layer.
2. The method of claim 1, wherein step (e) further comprises determining, from the calculated value of the parameter, an endpoint at which to terminate the process and thus cease changing the thickness of
20 the thin-film layer.
3. The method of claim 1, wherein the substrate is a semiconductor wafer and the thin-film layer is selected from a group consisting of an electrode layer, a metal layer, or an insulating layer
25 applied to the semiconductor wafer.
4. The method of claim 1, wherein the parameter is selected from a group consisting of a local maximum of the spectral-characteristic signal, a local minimum of the spectral-characteristic signal, a difference
30 of the local minimum from the local maximum, and a quotient of the local minimum to the local maximum.

5. The method of claim 1, wherein the parameter is selected from a group consisting of a largest local maximum of the spectral-characteristic signal, a smallest local minimum of the spectral-characteristic signal, a difference of the largest local minimum from the largest local maximum, and a quotient of the smallest local minimum to the largest local maximum.

6. The method of claim 1, wherein the parameter is a spectral dispersion of the spectral-characteristic signal.

7. The method of claim 1, wherein the parameter is a component of a Fourier transform of the spectral-characteristic signal.

8. The method of claim 1, wherein step (b) comprises detecting reflected signal light.

9. The method of claim 1, wherein step (b) comprises detecting transmitted signal light.

10. In a process for progressively reducing a thickness of a thin-film layer on a surface of a substrate, a method for detecting a process endpoint representing a minimum desired thickness of the thin-film layer, the method comprising:

- (a) directing a probe light onto a region of a surface of the thin-film layer to produce a signal light propagating from the thin-film layer;
- (b) detecting the signal light;
- (c) measuring a spectral characteristic of the signal light from the detected signal light to produce a spectral-characteristic signal;
- (d) calculating a cross-correlation function of the spectral-characteristic signal with a predetermined reference spectral-

characteristic signal, the cross-correlation function exhibiting a change with a corresponding change in the thickness of the thin-film layer; and

(e) from the cross-correlation function, determining the process endpoint.

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11. An apparatus for determining a process endpoint of a process for reducing a thickness of a thin-film layer on a substrate, the apparatus comprising:

- (a) a source of a probe light;
- 10 (b) a probe-light optical system configured and situated so as to direct the probe light to a location on a surface of the thin-film layer so as to produce a signal light propagating from the location;
- (c) a detector operable to detect the signal light;
- (d) a signal-light optical system configured and situated so as to
- 15 direct the signal light from the location to the detector; and
- (e) a signal processor connected to the detector, the signal processor being configured to measure a spectral characteristic of the signal light from the detected signal light, calculate a parameter of the spectral characteristic that is a function of the thickness of the thin-film
- 20 layer; and determine the thickness of the thin-film layer from the calculated parameter.

12. In a process for reducing a thickness of a thin-film layer on a surface of a workpiece, a method for detecting the thickness of the thin-film layer, comprising:

- (a) directing a probe light to a location on the thin-film layer so as to produce a signal light propagating from the location;
- (b) producing a signal waveform from the signal light;
- (c) calculating a value of a parameter of the signal waveform; and
- 30 (d) from the value obtained in step (c), calculating a thickness of the thin-film layer.

13. The method of claim 12, wherein the parameter is selected from the group consisting of a difference between a largest local maximum of the signal waveform and a smallest local minimum of the
5 signal waveform.

14. The method of claim 12, wherein the parameter is the smallest local minimum of the signal waveform.

10 15. The method of claim 12, wherein the parameter is a quotient of the smallest local minimum of the signal waveform to the largest local maximum of the signal waveform.

16. The method of claim 12, wherein the parameter is an average
15 of the signal waveform.

17. The method of claim 12, further comprising the steps of:
providing a reference value of the parameter corresponding to a reference thickness of the thin-film layer;
20 comparing the thickness determined in step (d) with the reference value to obtain a comparison value;
calculating, from the comparison value, a process endpoint at which to cease reducing the thickness of the thin-film layer.

25 18. The method of claim 12, further comprising the step of specifying on the thin-film layer a measurement position that includes the location, wherein step (a) is performed at the measurement position.

30 19. The method of claim 18, further comprising the steps of:
providing a reference value of the parameter corresponding to a reference thickness of the thin-film layer at the measurement position;

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comparing the thickness determined in step (d) with the reference value to obtain a comparison value;

calculating, from the comparison value, a process endpoint at which to cease reducing the thickness of the thin-film layer.

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20. The method of claim 18, further comprising the steps of:

providing a reference value of the parameter corresponding to a reference thickness of the thin-film layer at the measurement position;

10 comparing the thickness determined in step (d) with the reference value to determine an actual thickness of the thin-film layer at the measurement position; and

calculating, from the actual thickness, a process endpoint at which to cease reducing the thickness of the thin-film layer.

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21. The method of claim 12, further comprising the steps of:

obtaining an optical signal from a desired measurement position on the surface of the workpiece;

calculating a thickness of the thin-film layer; and

20 comparing the calculated thickness with a reference thickness at the measurement position so as to determine a process endpoint at which to cease reducing the thickness of the thin-film layer.

22. The method of claim 12, wherein the workpiece is a semiconductor wafer and the thin-film layer is either a metal layer or an insulating layer on the surface of the wafer.

23. In a process for reducing a thickness of a thin-film layer on an integrated circuit device formed on a surface of a semiconductor wafer, a method for detecting the thickness of the thin-film layer, comprising:

30 (a) directing a probe light to a location on the thin-film layer so as to produce a signal light propagating from the location, the signal light

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produced by either reflection of probe light from the thin-film layer or transmission of probe light through the thin-film layer;

(b) removing all orders of diffracted light from the signal light except a zeroth order of diffracted light;

5 (c) producing a signal waveform from the zeroth-order signal light;

(d) calculating a value of a parameter of the signal waveform; and

10 (e) from the value obtained in step (d), calculating a thickness of the thin-film layer.

24. The method of claim 23, wherein step (b) is performed by passing the signal light from the location through an aperture defined by an aperture plate, the aperture plate being configured and situated so as to block higher orders of diffracted light in the signal light.

25. The method of claim 24, including the step of varying a size of the aperture so as to cause the aperture to pass only the zeroth order of signal light.

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26. The method of claim 23, wherein step (b) is performed by providing a two-dimensionally distributed measurement of a spot pattern of the signal light while blocking the higher orders of signal light.

25 27. An apparatus for determining a process endpoint of a process for reducing a thickness of a thin-film layer on a substrate, the apparatus comprising:

(a) a source of a probe light;

30 (b) a probe-light optical system configured and situated so as to direct the probe light to a location on a surface of the thin-film layer so as to produce a signal light propagating from the location;

(c) a detector operable to detect the signal light;

(d) a signal-light optical system configured and situated so as to direct the signal light from the location to the detector;

5 (e) a plate situated in the signal-light optical system defining an aperture, the aperture being configured so as to remove all orders of diffracted light from the signal light except zero-order reflected light; and

10 (f) a signal processor connected to the detector, the signal processor being configured to measure a spectral characteristic of the signal light from the detected signal light, calculate a parameter of the spectral characteristic that is a function of the thickness of the thin-film layer; and determine the thickness of the thin-film layer from the calculated parameter.

15 28. The apparatus of claim 27, wherein the aperture is variable.

29. An apparatus for planarizing a surface of a workpiece, comprising:

20 (a) a polishing pad;
(b) a polishing head configured to support the workpiece and contact the workpiece against the polishing pad;
(c) a mechanism configured to move the polishing pad and the polishing head relative to each other as the workpiece contacts the polishing pad for polishing the workpiece; and
25 (d) an apparatus for determining a process endpoint as recited in claim 27.

30 30. A method for measuring a thickness of at least one of an insulating layer and a metal electrode layer on a surface of a semiconductor device undergoing a process in which the layer is being reduced in thickness, the method comprising the steps:

(a) illuminating a probe light onto at least a portion of a surface of the layer on the wafer so as to produce a signal light propagating from the layer, the layer being imprinted with a pattern;

(b) measuring an intensity profile of the signal light;

5 (c) determining a spatial coherence length of the signal light;

(d) comparing the spatial coherence length of the signal light with a degree of fineness of the pattern illuminated by the probe light;

(e) determining an optical model based on the comparison performed in step (d);

10 (f) calculating a theoretical intensity profile of signal light based on the optical model; and

(g) determining at least one of the thickness of the layer and a process endpoint by comparing the measured intensity profile of the signal light with the theoretical intensity profile of signal light.

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31. The method of claim 30, further comprising the step of varying the spatial coherence length of the probe light.

20 32. The method of claim 30, further comprising the step of varying the spatial coherence length of the probe light according to the degree of fineness of the pattern.

33. The method of claim 30, further comprising the step of storing the calculated theoretical intensity profile of signal light.

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34. The method of claim 30, wherein:

in step (f), the theoretical intensity profile of signal light is calculated for a thickness of multiple films having an inter-film distance therebetween; and

in step (g), the comparison is made based on a similarity between the calculated theoretical intensity profile of signal light and the measured change in the signal-light intensity profile.

- 5 35. The method of claim 30, further comprising:
calculating a cross-correlation coefficient of the theoretical
intensity profile of signal light and the measured intensity profile of signal
light; and

- 10 in step (g), the comparison is made based on a similarity between
at least one of a cross-correlation coefficient of a Fourier transform of
the theoretical intensity profile of signal light and the measured intensity
profile of signal light, and a position and magnitude of a Fourier
component of the calculated theoretical intensity profile of signal light
and a position and magnitude of a Fourier component of the measured
15 intensity profile of signal light.

- 20 36. In an apparatus for planarizing a surface on a semiconductor
wafer imprinted with a semiconductor device, an apparatus for
measuring a thickness of a layer on a surface of the semiconductor
device imprinted on the wafer so as to provide a planarizing process
endpoint, the apparatus comprising:

- (a) an illumination system configured to illuminate a probe light
onto a portion of the surface of the layer on the wafer so as to produce a
signal light propagating from the surface;
25 (b) a measuring system configured and situated to measure a
change in an intensity of the signal light;
 (c) a numerical calculation system connected to the measuring
system and configured to calculate a theoretical intensity profile of signal
light based on an optical model, the optical model being based on a
30 comparison of a spatial coherence length of the probe light with a degree

of fineness of a pattern for the semiconductor device illuminated with the probe light; and

- (d) a detection system configured and situated to detect at least one of a layer thickness and the process endpoint by comparing the
5 measured intensity profile of signal light with the calculated theoretical intensity profile of signal light.

37. The apparatus of claim 36, further comprising a controller connected to the numerical calculation system, the controller being
10 configured to control a spatial coherence length of the probe light.

38. The apparatus of claim 37, further comprising a storage system connected to the controller, the storage system being operable to store data concerning the calculated theoretical intensity profile of signal
15 light.

39. The apparatus of claim 36, wherein the detection system:
performs the comparison using a cross-correlation coefficient of the calculated theoretical intensity profile of the signal light and a
20 measured intensity profile of the signal light, and
performs a similarity comparison using at least one of a cross-correlation coefficient of a Fourier transform of the calculated theoretical intensity profile of the signal light and the measured intensity profile of the signal light, and a position and magnitude of a Fourier component of
25 the calculated theoretical intensity profile of the signal light and a position and magnitude of a Fourier component of the measured intensity profile of the signal light.

40. An apparatus for planarizing a surface of a workpiece,
30 comprising:

- (a) a polishing pad;

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(b) a polishing head configured to support the workpiece and contact the workpiece against the polishing pad;

(c) a mechanism configured to move the polishing pad and the polishing head relative to each other as the workpiece contacts the

5 polishing pad for polishing the workpiece; and

(d) an apparatus for determining a process endpoint as recited in claim 10.

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